



Knowledge in Motion  
SCI Education Series

**The Future is Here: What Can Robotics Do for Individuals with Spinal Cord Injury**



**Paolo Bonato, PhD**  
Harvard Medical School,  
Spaulding Rehabilitation Hospital  
MGH Institute of Health Professions,  
Harvard Medical School  
Wyss Institute for Biologically Inspired Engineering,  
Harvard University



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Spaulding Rehabilitation Hospital

Wyss Institute for  
Biologically Inspired Engineering



**THE FUTURE IS HERE: WHAT CAN  
ROBOTICS DO FOR INDIVIDUALS WITH  
SPINAL CORD INJURY**

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## DISCLOSURE

Dr Bonato serves as a member of the scientific advisory board of Hocoma AG. Dr Bonato does not receive compensation for this position.

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## TECHNOLOGY TO SERVE HUMANITY



Engineers are working for you ...



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## THE TECHNOLOGY IS "BROKEN"

**"Humans are not disabled. A person can never be broken. Our built environment, our technologies, are broken and disabled. We the people need not to accept our limitations, but can transcend disability through technological innovation."**

**Hugh Herr**



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## THE TECHNOLOGY IS "BROKEN"



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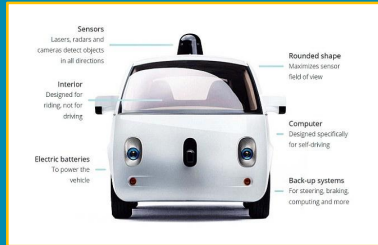


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## THE FUTURE IS HERE ...



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## THE FUTURE IS HERE ...



Homayoon Kazerooni  
UC Berkeley



Gregoire Courtine  
EPFL



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## UNDERSTANDING REHABILITATION ROBOTICS

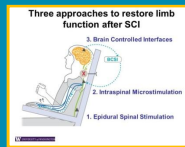
Retraining



Augmenting



Restoring



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## RETRAINING UPPER LIMB MOTOR FUNCTION

[Video Clip]

Barrett Technology

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## RETRAINING UPPER LIMB MOTOR FUNCTION



Armeo Power, Hocoma



Robert Riener  
ETH

### Pros

- Efficacy data in many populations.
- Advanced control techniques.



MIT Manus



Neville Hogan  
Igo Krebs  
MIT

### Cons

- Limited efficacy data in SCI.
- Current use marked by low dosage.

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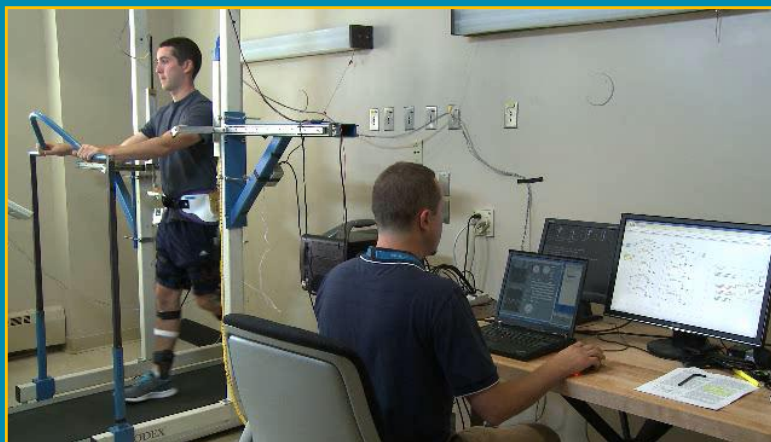


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## RETRAINING LOWER LIMB MOTOR FUNCTION



Northeastern University and  
Spaulding Rehabilitation Hospital

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## RETRAINING LOWER LIMB MOTOR FUNCTION



Lokomat, Hocoma



Gery Colombo  
Hocoma

### Pros

- Good efficacy data in SCI.
- Progress in control techniques.



GEO, RehaTechnology



Stefan Hesse  
Univ Berlin

### Cons

- Training does not challenge balance.
- Current use marked by low dosage.

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## THE ROBOTIC GYM

Toward the implementation of high-dosage interventions ...



Courtesy of Hocoma

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## AUGMENTING UPPER LIMB MOTOR FUNCTION



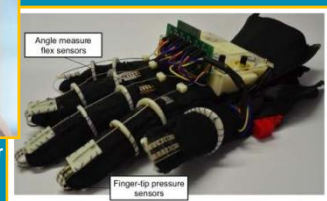
Myomo



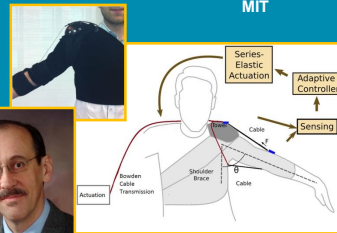
Harry Asada  
MIT



Gregory Fischer  
WPI



Robert Howe  
Harvard Univ



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## AUGMENTING LOWER LIMB MOTOR FUNCTION



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## AUGMENTING LOWER LIMB MOTOR FUNCTION



Cyberdine



Homayoon  
Kazerooni  
UC Berkeley



EksoBionics



SuitX Phoenix



ReWalk



Indego



Michael  
Goldfarb  
Vanderbilt



Conor Walsh  
Wyss Institute

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## WEARABLE ROBOTS IN THE FIELD

Monitoring the use of wearable robotic systems in the home and community settings is of paramount importance. It is essential to assure users' safety and to gather data to continue to improve the reliability of such systems.



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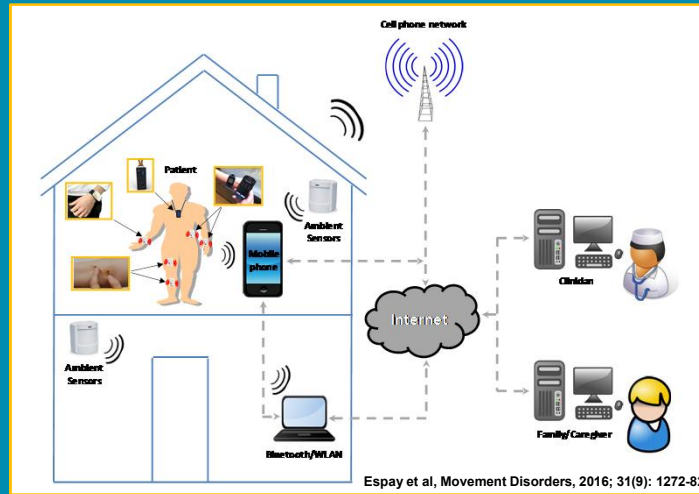


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## WEARABLE ROBOTS IN THE FIELD



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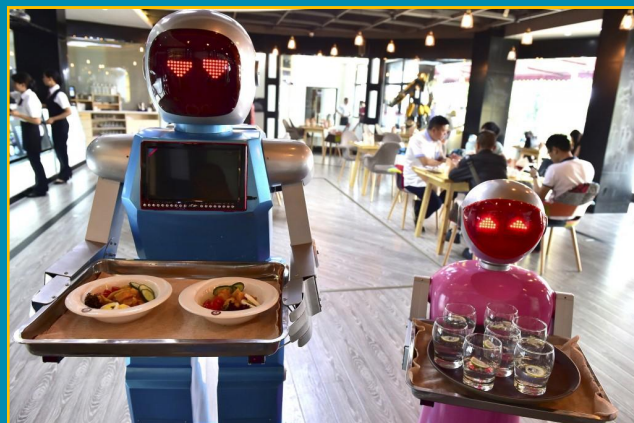


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## SERVICE ROBOTS



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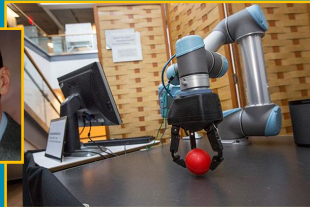
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## SERVICE ROBOTS



Robert Howe  
Harvard Univ



Kinova Robotics



William Townsend  
Barrett Technology



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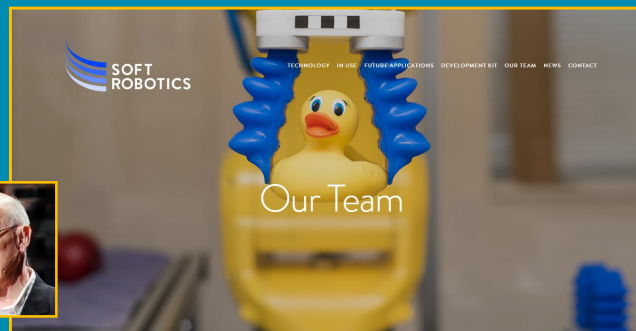


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George  
Whitesides  
Harvard Univ

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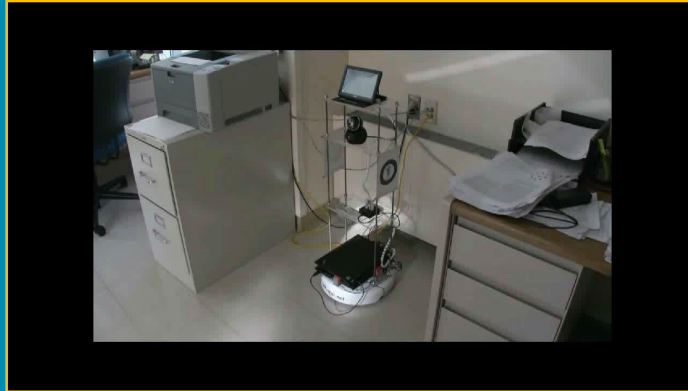
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## SERVICE ROBOTS



Alessandro  
Puiatti  
SUSPI



Spaulding Rehabilitation Hospital  
SUSPI (University of Applied Sciences and Arts of Southern Switzerland)  
Wyss Institute, Harvard University

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## SERVICE ROBOTS



Dean Kamen  
DEKA (partnership with Toyota)



Jose del Milan  
EPFL

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## RESTORING FUNCTION

### Walking again after spinal cord injury

Researchers at EPFL have successfully used electrochemical stimulation to restore voluntary movement following a paralyzing spinal cord injury. After only a few weeks of stimulation, nerve connections begin to grow again. Now that this principle has been demonstrated on rats, it may one day offer patients with spinal cord injuries hope for functional improvement of their condition.

- Awakening**  
A combination of electrical and chemical stimuli awakens the nervous system below the lesion.
- Training**  
A mechanical harness vertically supports the rat. After a few weeks of training, the rat can perform voluntary movements under electrochemical stimulation.
- Regrowth of the nerve fibers**  
The central nervous system repairs itself, not only near the injury, but also in the brain, to restore contact.

### Primates Regain Control of Paralyzed Limb

Non-human primates regain control of their paralyzed limb. A neuroprosthetic interface serves as a wireless bridge between the brain and spine, completely bypassing the injury.

- Brain implant**  
A neuroprosthetic array is implanted in the brain, with electrodes for the cortical motor cortex for the upper limb, and for the right leg. It records motor cortex spiking activity and sends the data to a computer.
- Decoding Motor States**  
A computer interprets the neural activity of the motor cortex as motor states which are sent to a pulse generator.
- Pulse generator**  
The pulse generator configures stimulation protocols based on the decoded motor states which is powered by the primate's multi-limbic system.
- Spinal implant**  
The multi-electrode array is surgically placed over the spinal cord below the injury. Each electrode stimulates a specific neural pathway that controls a group of muscles.



Gregoire Courtine at EPFL is developing techniques in animal models that he hopes to be able to use in patients in the future.

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## RESTORING FUNCTION



### BREAKTHROUGH THAT OFFERS HOPE FOR MILLIONS

- 1** A tiny chip implanted in Bill Kochevar's brain reads his thoughts about moving his hand.
- 2** The signals are sent to a computer processor which converts them into instructions for his muscles.
- 3** Messages are sent to electrodes implanted in muscles in his shoulders, biceps and forearm.
- 4** The muscles contract and he moves his arm, hands and fingers.

Robert Kirsch, Case Western Univ

Restoration of reaching and grasping movements through brain-controlled muscle stimulation in a person with tetraplegia: a proof-of-concept demonstration



The Lancet  
March 28, 2017

A Bolu Ajiboye\*, Francis R Willett\*, Daniel R Young, William D Memberg, Brian A Murphy, Jonathan P Miller, Benjamin L Walter, Jennifer A Sweet, Harry A Hoyen, Michael W Keith, P Hunter Peckham, John D Simeral, John P Donoghue, Leigh R Hochberg, Robert F Kirsch

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## CONCLUSIONS

- Although the technology is “broken” ... the future is here.
- Robotic technology provides unique opportunities to retrain, augment, and restore motor function.
- The implementation of high-dosage retraining interventions could be tremendously facilitated by robotics.
- The use of wearable robots for augmentation is becoming reality and safe thanks to sensor-based remote monitoring.
- Many technologies are enabling the restoration of function via “repair” as well as via bypassing spinal lesion areas.

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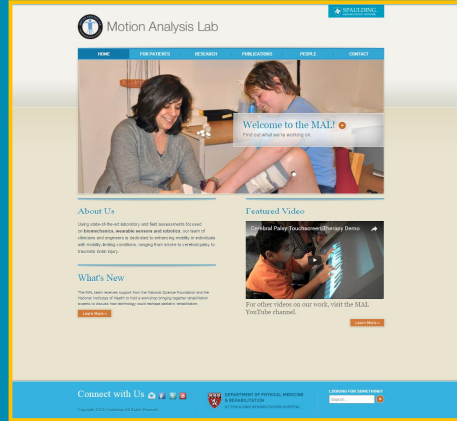
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## Knowledge in Motion Q & A

### The Future is Here: What Can Robotics Do for Individuals with Spinal Cord Injury



**Paolo Bonato, PhD**  
**Tim Morris, Consumer**  
**Erick Larson, Consumer**  
**Katie Schramm, DPT**  
**Anne O'Brien PT,**  
**Catherine Adans-Dester, RA**

